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MEASUREMENT OF THE TEMPERATURE

OF THE DETONATION FRONT

OF EXPLOSIVE SUBSTANCES

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Calculation of the parameters of the detonation wave shows that the detonation temperature is the value most sensitive to the form of equation of state of explosion products, and knowledge of it is necessary in the verification of the latter. Up to the present time, however, little work has been published on experimental determination of the detonation temperature. We undertook measuring the temperature of the detonation front from the front in transparent and semi-transparent charges of liquid and solid explosive substances by the electronic-optical method.

Measurement of the detonation temperature in transparent liquid explosive substances

The luminescence of the detonation front in a charge of liquid explosive substance placed in a Plexiglas flask with a transparent bottom was recorded from the frontal surface by means of a FEU-29 M photomultiplier whose cur-

rent was registered on an oscillograph with a single OK-17 M scanner. In the investigation of luminescence of detonation fronts in nitromethane and methyl nitrate it was found that they have spectra (in the region of 400-600 mμ) similar to the spectra of black bodies with a temperature of 3700 and 4500° K respectively and equal emission coefficients. The latter permits us to suppose that the detonation front shines like a black or gray body and that it is possible therefore to measure the temperatures by a chromatic method consisting of comparison of the brightness of the luminescence in the two sections of the spectrum (in our case behind light-filters SS-5 and ZS-1).

In the experiment measurement was made of the relationship

$$\frac{\Sigma_{CC-5}}{\Sigma_{C3-1}} = \int_{\lambda_1}^{\lambda_2} S_\lambda b_\lambda \cdot \tau_{CC-5} \, d\lambda \Big/ \int_{\lambda_1}^{\lambda_2} S_\lambda b_\lambda \cdot \tau_{3C-1} \, d\lambda.$$

$$CC = SS$$
$$3C = ZS$$

where S_λ is the spectral sensitivity of the photomultiplier, b_λ the spectral brightness of the source, τ_{SS-5} and τ_{ZS-1} the emission coefficients of the light-filters, λ_1 and λ_2 the limits of spectral sensitivity of the photomultiplier, and the temperature was found according to a graduated graph of the relationship of $\frac{\Sigma\,ss-5}{\Sigma\,zs-1}$ to the reciprocal of the temperature of the source, constructed by calculation for an absolutely black body. With the aid of a standard source of light a preliminary calculation was made of the spectral sensitivity of the photomultiplier and the emission coefficient of the optical system.

The maximum error in measurement of the relationship $\frac{\Sigma_{SS-5}}{ZS-1}$ of the detonation front of transparent liquid explosive substances amounted to 3%, which represents an error in measurement of temperature not greater than 150° K. Table 1 shows us for the detonation front, the initial density ρ_o and the rates of detonation for a number of liquid and solid explosive substances. The rates of

detonation D were determined with an accuracy of up to
100m/sec either by the electrical contact or by the optical
method. The accuracy of measurement of the detonation
temperature for solid explosive substances is 300° K.

Table 1

Substance	Density (g/cc)	Temp. (°K)	D (m/sec)
Nitroglycerin	1.60	4000	7650
Nitroglycol	1.50	4400	7400
Methyl nitrate	1.21	4500	6750
Nitromethane	1.14	3700	6300
Tetranitromethane	1.64	3100	5400
Hexogen	1.79	3700	8800
TEN	1.77	4200	8500
DINA	1.70	3700	8000

Measurement of the detonation temperature in semi-transparent charges of solid explosive substances

In the same way as measurements were made of the de-
tonation front in transparent charges of liquid explosive
substances it is possible to measure temperatures in semi-
transparent charges of solid substances with a density
near a monocrystal. As in the first case, the luminescence
is recorded upon the emergence of the detonation wave on
the face of the charge, which does not permit making a
measurement of the absorption of light in the charge.
But the slight transparence of the charge and the bright
luminescence of the shock wave of the air during the dis-
persion of explosion products from the face makes it
difficult to determine the moment of emergence of the wave
exactly. The face of the charge is placed in water in
order to intercept the luminescence of the air shock wave.
Special attention was given in the experiments to the ab-
sence of fissures in the charge and the adhesion of air
to the facial surface of the charge.
In comparison of the brightness of the luminescence
or detonation fronts in investigations of explosive sub-
stances in the area of the spectrum of 400-600 mμ it was
found that their relationship is the same as it must be
for absolutely black bodies at these temperatures (this

corresponds to one and the same emission coefficient of the detonation front). This enables us, in measuring temperatures by the chromatic method, to check it all the time by comparing the brightness of luminescence of the detonation of the explosive substance being investigated with the brightness of luminescence of any explosive substance studied previously (practically a brightness method of measuring temperatures). Since the emission coefficient of the detonation front does not change from substance to substance, and the temperature changes from 3500 to 5000° K, it can be assumed that it is near unity.

Discussion of the results

Of previously published work on the experimental determination of detonation temperatures, reference should be made to that of Alentsev, Belyaev et al. [1] , who first measured the detonation temperatures of liquid explosive substances, and to the more recent work of Gibson et al. [2] , who used light conductors, weakly shining charging and the electro-optical method to measure detonation temperatures. The detonation temperatures of nitromethane and nitroglycerin obtained by us agree with the results in [2] and the temperatures of hexogen and TEN differ.

The measured detonation temperatures are too large to be attributed to luminescence of non-reactive shock front preceding the detonation complex. Because of the small depth of the reaction zone in powerful explosive substances with rapid growth of the reaction rates in it, and the strong dependence of brightness of the luminescence on temperature, it can be assumed that these temperatures are very near those which will be in a Chapman-Juge plane.

By using the temperatures obtained, and likewise the experimental values of the pressure [3] during detonation of TEN (ρ_o = 1.77 g/cc, p = 340.10³ atm), hexogen (ρ_o = 1.79 g/cc, p = 390.10² atm), nitroglycerin (ρ_o = 1.60 g/cc, p = 250.10³ atm) and nitromethane (ρ_o = 1.14 g/cc, p = 133.10³ atm) it is possible to check the different types of equations of state of the explosion products. The data given do not confirm the values calculated in papers [4-7] .

Recently in Cook's work [4, 8] there is extensive use of the equation of state $pv = nRT + p.a(v)$, where n is the number of mols per gram of products, R is the gas constant, v is the specific volume of the products in the Chapman-Juge plane. With this form of the equation of state, proceeding from our data for pressure and temperature, it would be possible to assume an expression for the co-volume $a(v) = v(1.08-0.40v)$, which, it is true, does not agree with the numerical values given in [8]. With a co-voluminous equation of state the equation of the conservation of energy is not satisfied: $E - E_0 = Q + \frac{1}{2}$ $p(v_0-v)$, where Q is the heat of explosion taken from [8]. In the latter equation the internal energy is $E = \int c_v dT$

where c_v was calculated for an ideal gaseous state of the explosion products [since $(\frac{\partial c_v}{\partial v})_T = T(\frac{\partial^2 p}{\partial T^2}) = 0$].

This indicates that the co-voluminous equation $pv = nRT + p.a(v)$ is not a satisfactory equation of state for the explosion products (especially at large p) and can be considered only as somewhat of an approximation suitable for calculating p, v or T when two of these values are known. It is entirely probable that obtaining the co-voluminous equation of state for the explosion products on the basis of the data for nitromethane, nitroglycerin, hexogen and TEN became possible as a result of these close detonation temperatures.

If, following Landau and Stanyukovich [9], terms are introduced into the energy and pressure equations which take into consideration the mutual repulsion of the molecules at high pressures, and we write $E = \int^T c_v dT + E_{simp}$ and $p = \frac{nRT}{v} + p_{simp}$, then the values

of E_{simp} for nitromethane, nitroglycerin and hexogen $\rho_0 = 1.60$ g/cc) will be 4, 37 and 50% respectively of E. At the same time nRT changes little and for nitromethane is 23.10^3 atm, nitroglycerin 24.10^3 atm and hexogen 28.10^3 atm, which averages 17.3, 9.2 and 7.2% of the values of pressure p. The results obtained indicate the importance of experimental determination of temperature for deriving

and checking the equation of state for explosion products and the expression for the internal energy, without which it is difficult to calculate the parameters of the detonation wave.

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